4.2 OBSERVATIONS OF GRAVITY WAVE SCALES, FLUXES, AND SATURATION DURING MAP

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During the MAP/MAC period, considerable improvements in instrumentation and experimental technique have occurred, and many hitherto unavailable parameters relating to gravity waves have become available. Studies of individual wave events and simultaneous observations made with a variety of techniques have provided insight into wave saturation mechanisms. In addition, long data sets of upper middle atmosphere winds have been collected at a number of widely spaced sites, allowing climatological investigations of gravity wave amplitudes, wave number spectra, polarization, mean flow acceleration, and other saturation effects to be undertaken. In this paper, observations of gravity wave scales, momentum fluxes, saturation and saturation effects obtained during MAP/MAC, made on both a statistical and case study basis are reviewed.

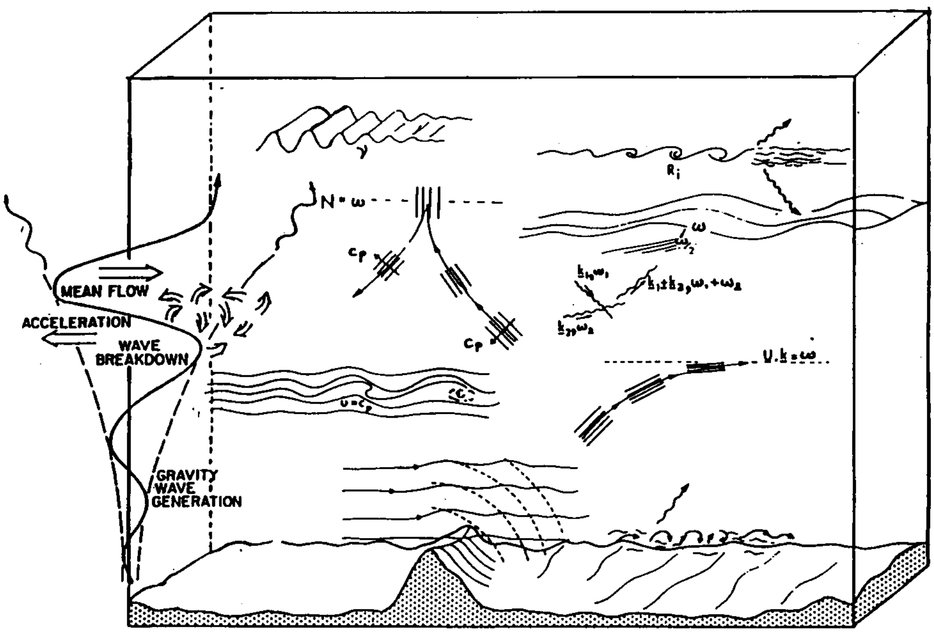


Figure 1. Schematic diagram showing processes whereby gravity waves interact with each other and with the background wind. (Adapted from a diagram by S. A. Thorpe).

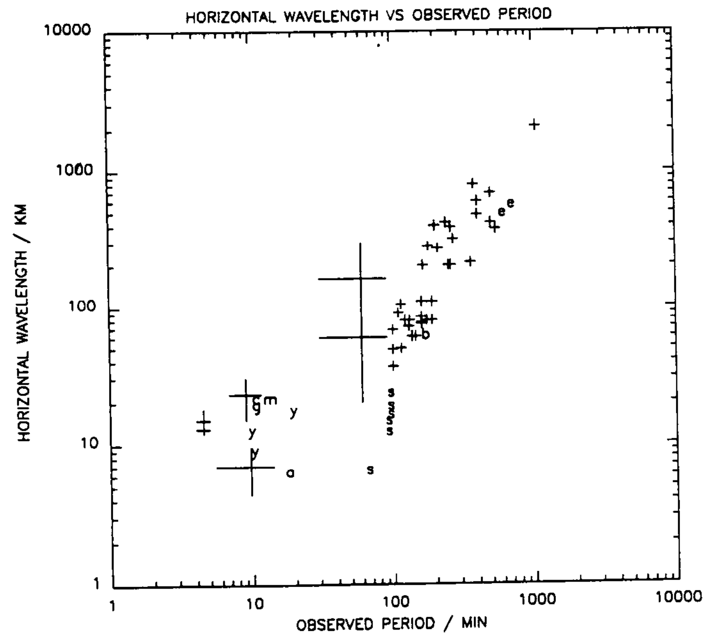


Figure 2. Collation of tropospheric and stratospheric observations of horizontal scale shown as a function of observed period.

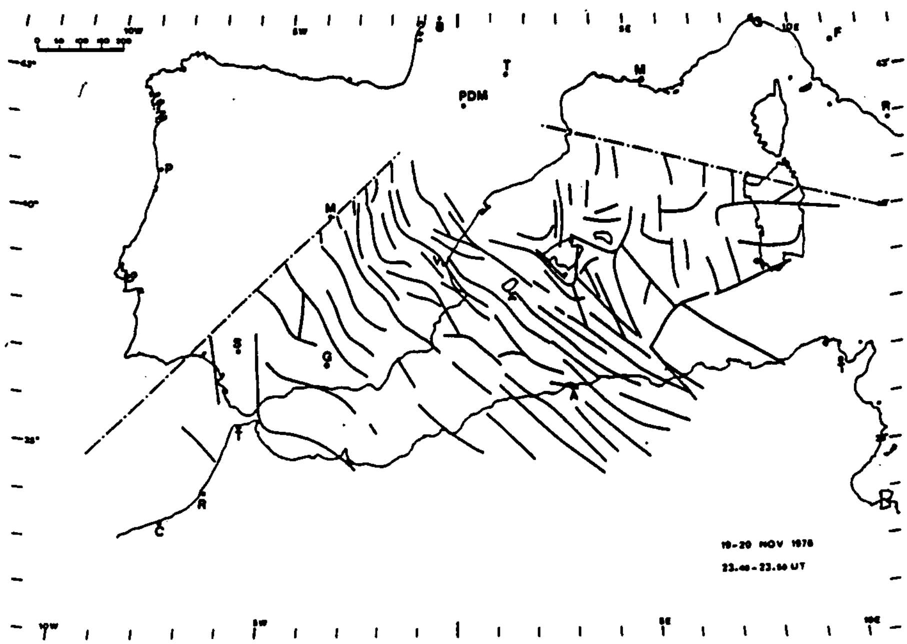
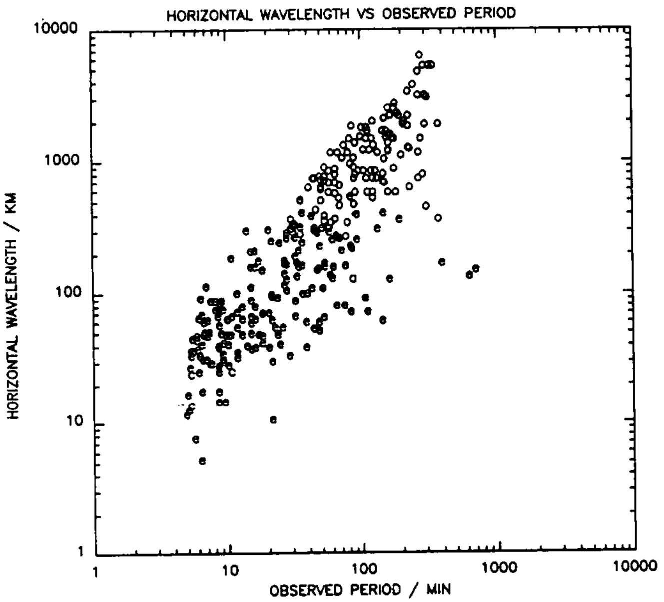


Figure 3. Bright crests evident in 558 nm airglow generally believed to be associated with the passage of gravity waves. [After Herse et al., *Appl Opt.*, *19*, 355, 1980].



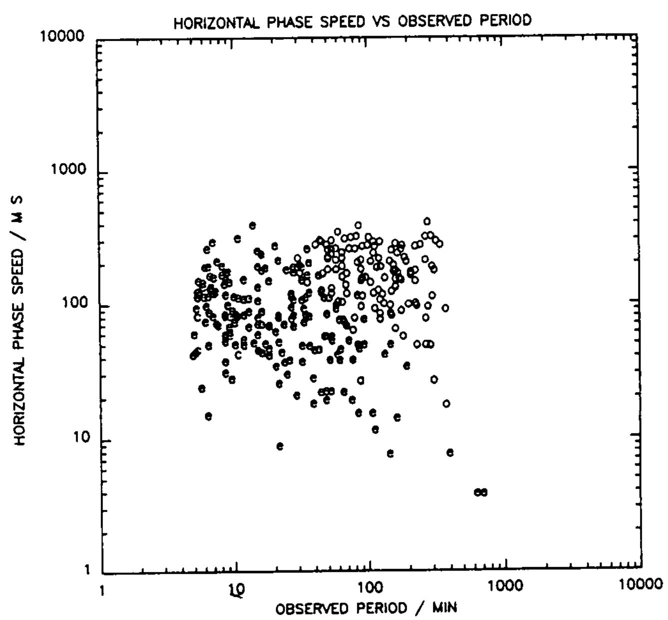


Figure 4. (a) Collation of 558 nm (~ 95 km) measurements of gravity wave horizontal scale shown as a function of observed period. (b) As for Figure 4(a) but for horizontal phase speed.

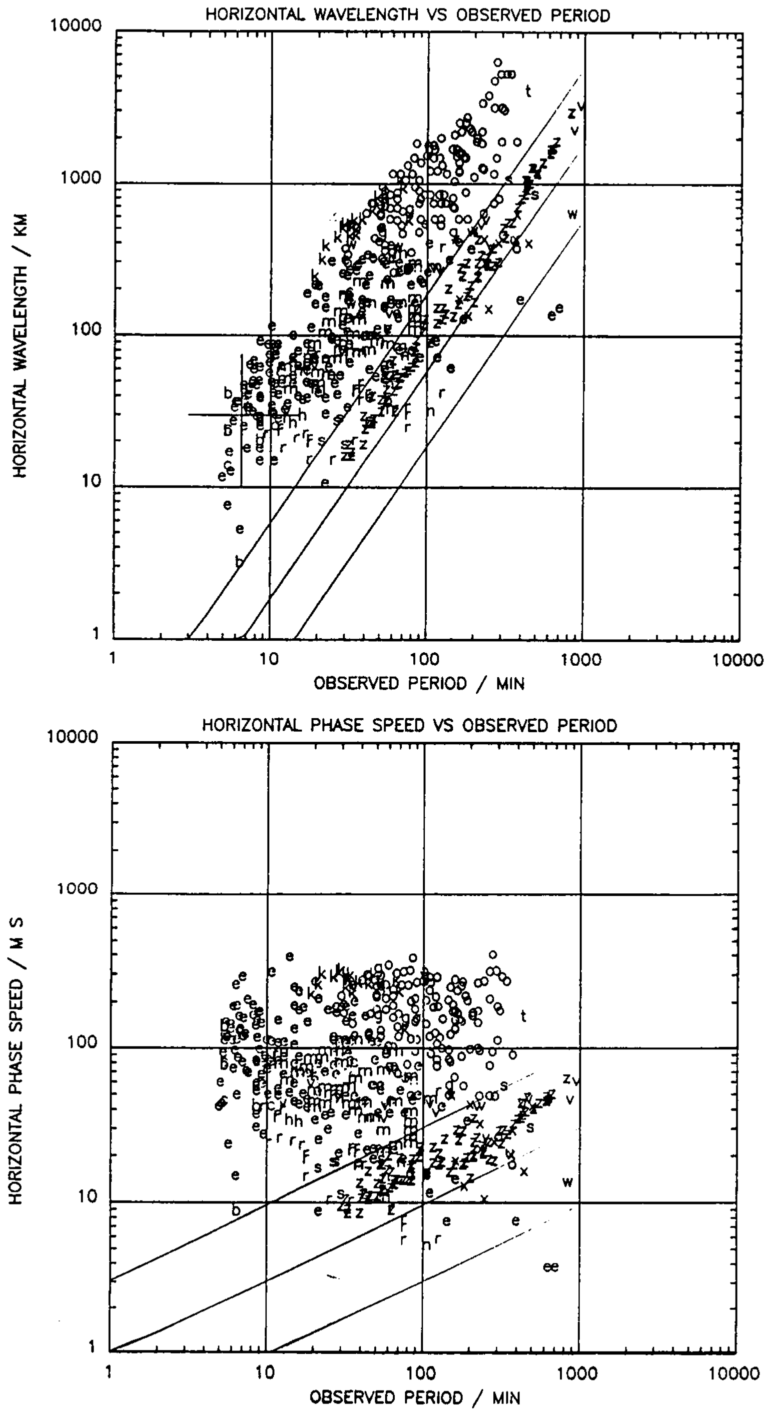


Figure 5. (a) Collation of radar and optical observations of mesospheric and lower thermospheric gravity wave horizontal scales. (b) As for Figure 5(a) but for horizontal phase speed.

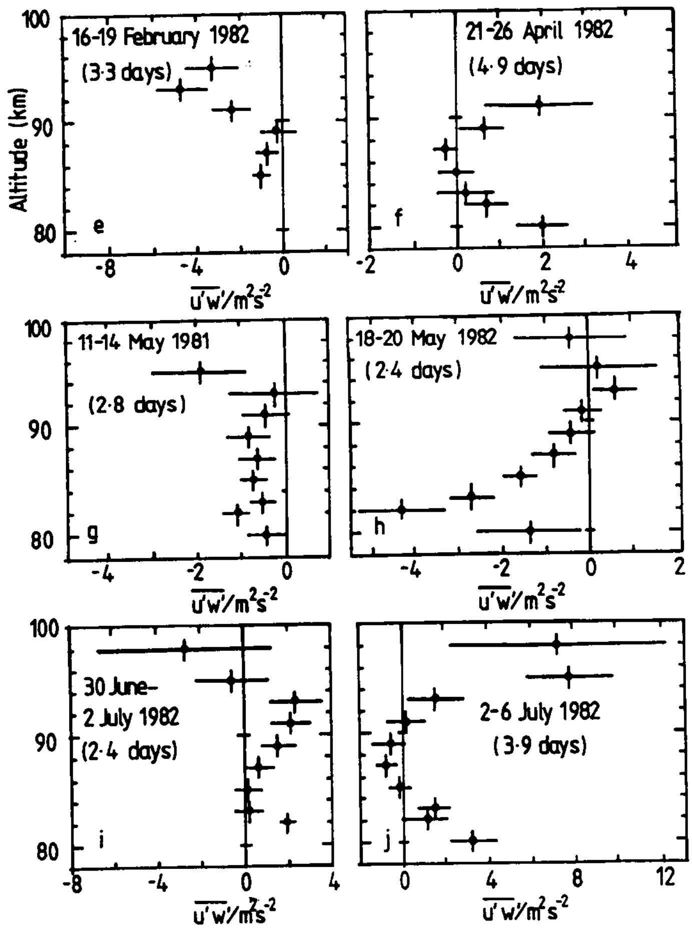


Figure 6. Measurements of the upward flux of zonal momentum obtained at Adelaide (35°S) in six different observational periods. [After Reid and Vincent, *J. Atmos. Terr. Phys., 49,* 1987].

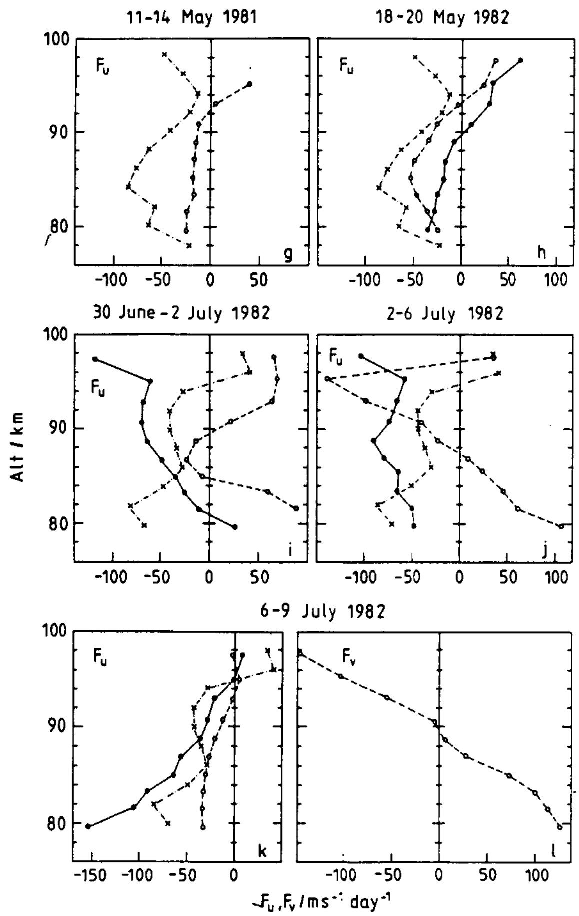


Figure 7. Zonal (F_u) and meridional (F_v) mean flow accelerations measured at Adelaide (open circles), the Coriolis torque due to the mean meridional wind component for the same period reversed in sign (solid circles), and for the monthly mean values measured at Adelaide between 1978-1983 (crosses). [After Reid and Vincent, *J. Atmos. Terr. Phys.*, *49*, 1987].

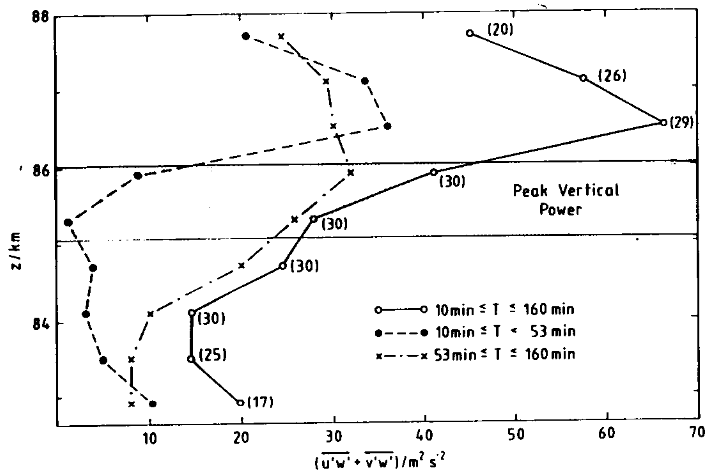


Figure 8. Total upward flux of horizontal momentum measured in a three hour period over Andoya, Norway, using the mobile SOUSY VHF (53.5 MHz) radar. The shaded area indicates the 3 dB of the radar echo. [After Reid et al., *Geophys. Res. Lett.*, 1988, in press].

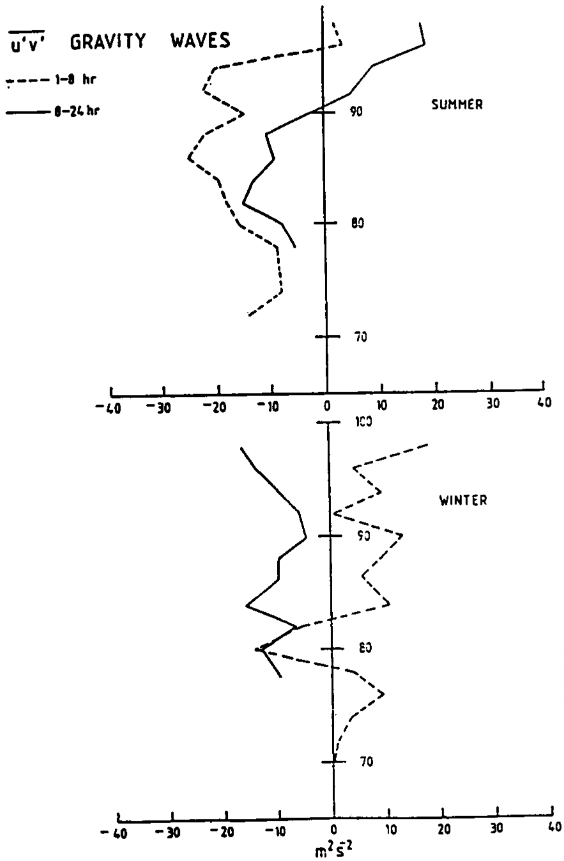


Figure 9. Horizontal transport of horizontal momentum measured at Adelaide. [After Vincent and Fritts, *J. Atmos. Sci.*, *44*, 1987].

Vertical Energy Flux

Gossard	leaving troposphere	100 mW m^{-2}
Chanin and Hauchecorne	50 km	30 mW m^{-2}
Vincent	85 km	12-13 mW m^{-2} (mid and low latitudes) 29 mW m^{-2} (high latitude)
Gavrilov and Kalov	90 km	1-6 mW m^{-2}
Gavrilov and Shved	95 km	1-8 mW m^{-2}
Jacobs and Jacka	95 km	15 mW m^{-2}

Maximize in Winter
Maximize at high frequencies (periods less than ~1h)

Figure 10. Measurements of the gravity wave vertical energy flux at various heights through the atmosphere.

Parameter	Range of values	Parameter	Range of values
τ	0.5-6 hrs	F_{xz}	1-4 m^{2}s^{-2}
V	6-20 m s^{-1}	F_{yz}	1-10 m^{2}s^{-2}
λ_{11}	100-800 km	F_{xy}	2-20 m^{2}s^{-2}
λ_z	10-30 km	F_{Tx}	1-20 erg cm^{-2}s^{-1}
$\underline{c}$	20-160 m s^{-1}	F_{Ty}	1-200 erg cm^{-2}s^{-1}
$\underline{F}_z$	1-6 erg cm^{-2}s^{-1}	F_{Tz}	1-6 erg cm^{-2}s^{-1}
$\underline{F}_x$	1-20 erg cm^{-2}s^{-1}	F_{mx}	2-10 10^{-8}kg m^{-2}s^{-1}
$\underline{F}_y$	1-10 erg cm^{-2}s^{-1}	F_{my}	1-4 10^{-6}kg m^{-2}s^{-1}
		F_{mz}	1-3 10^{-8}kg m^{-2}s^{-1}

Figure 11. Summary of gravity wave characteristics obtained using meteor radars. Note that erg cm^{-2} s^{-1} ≡ mW m^{-2}. [After Gavrilov, *Handbook for MAP, 25,* 1988].

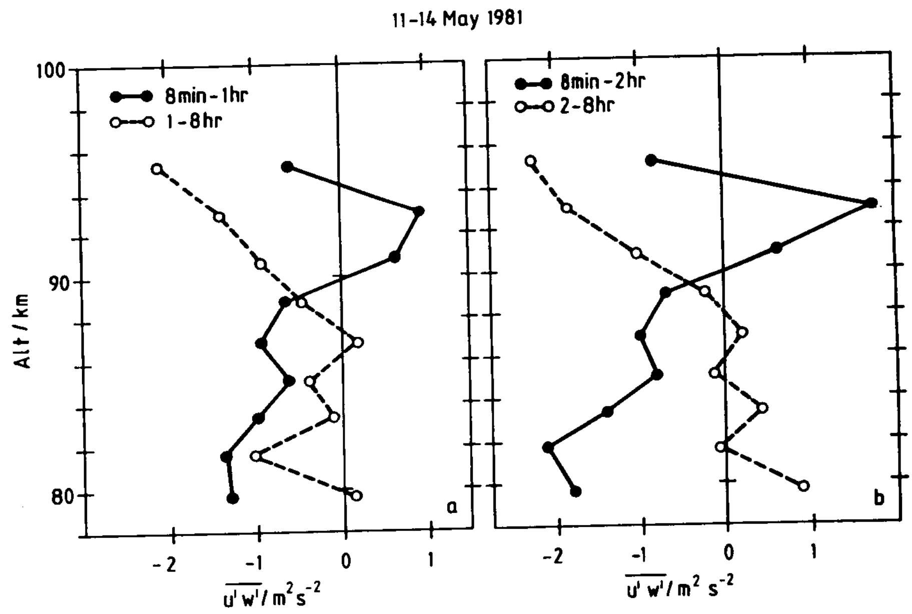


Figure 12. Contributions to the upward flux of horizontal momentum for different period ranges for observations made at Adelaide. Short period motions (≤ 1 h) contribute approximately 70% of the total flux. [After Reid and Vincent, *J. Atmos. Terr. Phys.*, *49*, 1987].

FOR SHORT (OBSERVED) PERIOD GRAVITY WAVES ($\lesssim$1 h)

- SCALE FOUND TO INCRESE FROM ABOUT 30 KM AT 10 MIN TO ABOUT 80 KM AT 100 MIN (SUGGESTS 20 AND 55 KM RESP. FOR ISOTROPIC WAVEFIELD)
- VALUES OF $\overline{u'w'}$ UP TO $3m^2s^{-2}$ FOUND TO BE ASSOCIATED WITH THESE WAVES, BUT MORE TYPICAL VALUES ARE ABOUT $1m^2s^{-2}$
- FLUX CONVERGENCE ASSOCIATED WITH INDIVIDUAL SHORT PERIOD GRAVITY WAVE EVENTS APPEARS EASILY ABLE TO PROVIDE SUBSTANTIAL (~50 $ms^{-1}day^{-1}$) MEAN FLOW ACCELERATION
- 89% OF VALUES OF ZONAL SCALE LESS THAN 80 KM
- 87% OF ZONAL PHASE VELOCITIES WITHIN 60 ms^{-1} OF ZERO
- MOST LIKELY ZONAL PHASE SPEED (44%) LAY IN 20–39 ms^{-1} INTERVAL

FOR 8 MIN–8H PERIOD BAND

- WHEN AVERAGED OVER PERIODS OF 2–5 DAYS, MAGNITUDE OF $\overline{u'w'}$ TYPICALLY LESS THAN $3m^2s^{-2}$
- LARGEST VALUES OBSERVED IN WINTER AND SUMMER
- ABOUT 70% OF $\overline{u'w'}$ DUE TO PERIODS LESS THAN 1H AND CONTRIBUTION TO F_u IS COMPARABLE
- ZONAL MEAN FLOW ACCELERATION OFTEN IN CORRECT SENSE AND OF SUFFICIENT MAGNITUDE TO DECELERATE THE ZONAL WIND COMPONENT AND TO BALANCE THE CORIOUS TORQUE DUE TO THE MEAN MERIDIONAL WIND
- WHEN AVERAGED OVER PERIODS OF AROUND 3 DAYS, VALUES OF F_u UP TO 190 $ms^{-1}day^{-1}$ WERE CALCULATED, BUT MORE TYPICAL VALUES ~50–80 $ms^{-1}day^{-1}$
- VALUES OF $\overline{u'w'}$ AND $\overline{v'w'}$ FOUND TO BE SIMILAR

Figure 13. Summary of characteristics of individual short period (≤ 1 h) gravity waves (top), and of motions in the 8 min - 8 h period band (bottom) measured at Adelaide by Reid and Vincent [*J. Atmos. Terr. Phys., 49,* 1987].

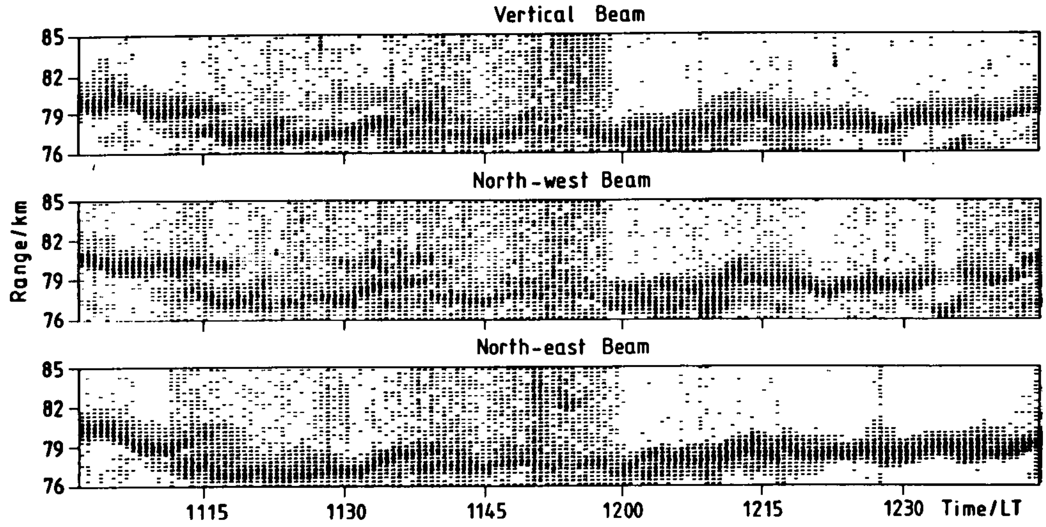


Figure 14. Cat's-eye-like structures consistent with dynamical instability observed at Andoya with the mobile SOUSY radar on 1 February 1984 in three different beam directions. [After Reid et al., *Nature, 327,* 1987].

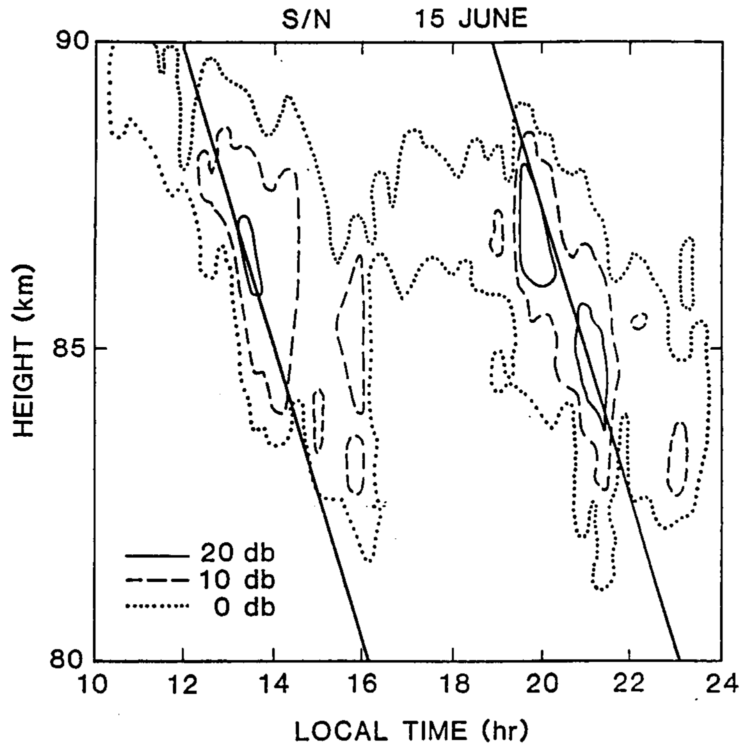


Figure 15. Power measured during the STATE campaign with the Poker Flat VHF (50 MHz) radar. The diagonal lines indicate the region of maximum instability induced by a long period gravity wave. [After Fritts et al., *J. Geophys. Res.*, 1988, in press].

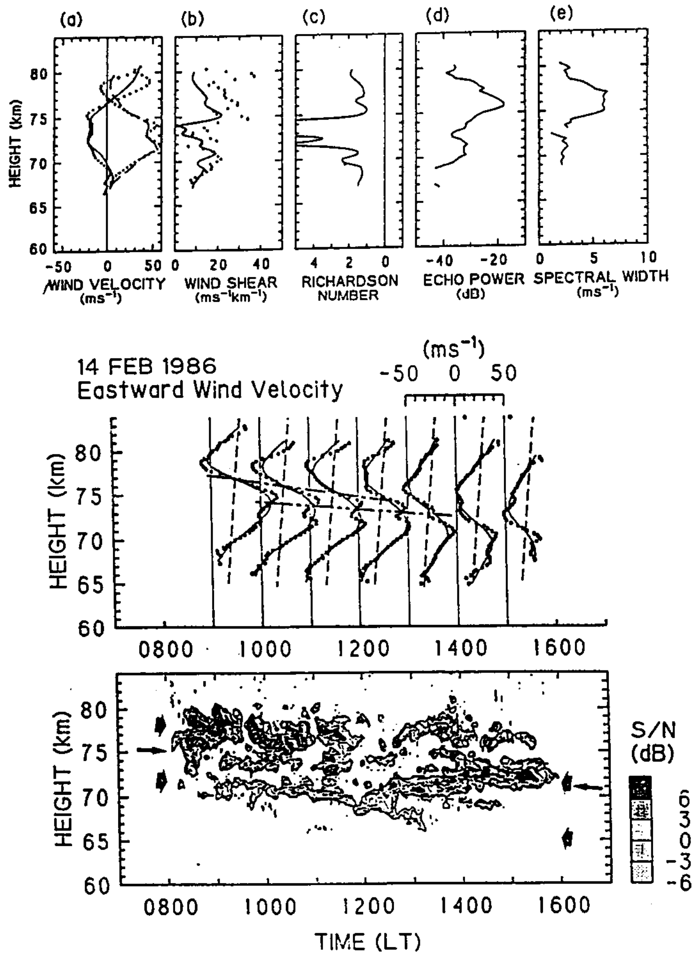


Figure 16. (top) Wind velocity, shear, wave modified Richardson number, echo power and spectral width, (center) Vertical wind profiles of the corresponding inertia period gravity wave, and (bottom) The echo power as a function of height and time measured using the MU VHF radar [After Yamamoto et al., *Physica Scr.*, 1988, in press].

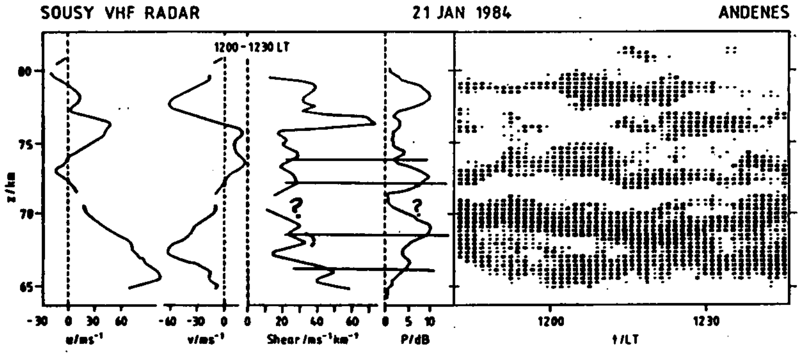


Figure 17. (left) Horizontal wind components, the shear and mean power measured between 1200-1230 LT at Andoya on 21 January 1984, and (right) A height-time intensity plot of the backscattered power for approximately the same interval. [After Czechowsky et al., submitted to *Geophys. Res.*, 1988].

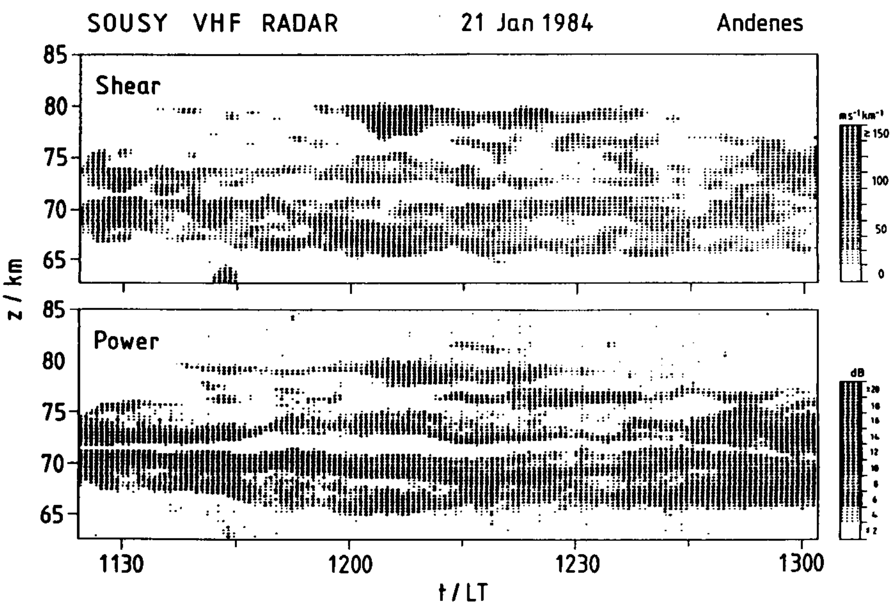


Figure 18. Height-time intensity plot of shear (top) and backscattered power (bottom) on 21 January 1984 at Andoya. [After Czechowsky et al., submitted to *Geophys. Res.*, 1988].

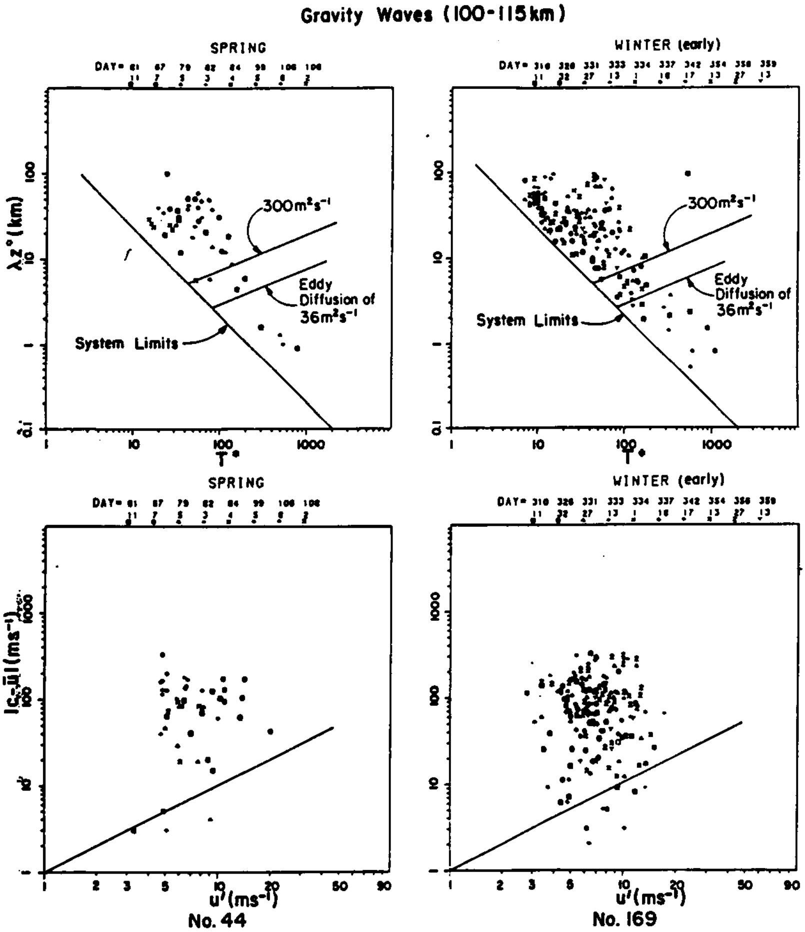
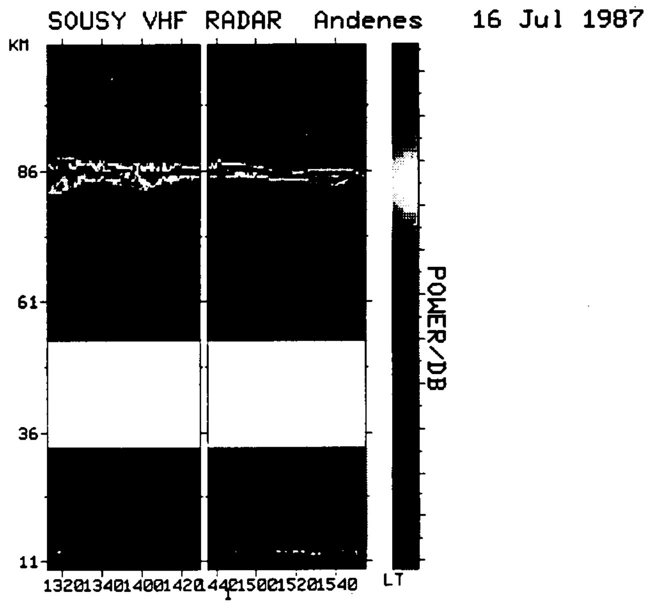


Figure 19. Gravity wave characteristics measured at Saskatoon, Canada. The condition for convective instability of monochromatic gravity waves $|c-\bar{u}| > u'$ is rarely met. [After Manson and Meek, *J. Atmos. Sci.*, 1988].

GRAVITY WAVES IN THE UPPER MIDDLE ATMOSPHERE PRODUCE

- ZONAL MEAN FLOW ACCELERATION AND BALANCE CORIOLIS TORQUE DUE TO MEAN MERIDIONAL WIND
- TURBULENCE → SCATTERING IRREG.
- HEATING/COOLING
- SOME FORMS OF SCATTERING STRUCTURES
- VARIATIONS IN EDDY DIFFUSIVITY/ADVECTION AND HENCE MINOR CONSISTUENT CONCENTRATIONS
- SOME VARIATIONS IN AIRGLOW INTENSITY IN TIME/SPATIALLY PERHAPS SEASONALLY/LATITUDINALLY



THEY ARE

- UBIQUITOUS (High Frequency)
- ENERGETICALLY MOST IMPORTANT AT LOW FREQUENCIES
- MOST IMPORTANT FOR VERTICAL TRANSPORT OF MOMENTUM AT HIGH FREQUENCIES
- DIFFICULT TO OBSERVE - OFTEN SUPERIMPOSED
- SUBJECT TO DISSIPATION/DIFFUSION SATURATION/BREAKING
- GENERATED IN TROPOSPHERE ($\geq$65% long period)
- TRANSIENT IN SENSE THAT MEAN FLOW ACCELERATIONS OCCUR SPORADICALLY

Figure 20. Summary of same gravity wave characteristics in the upper middle atmosphere.